Effects of added nitrogen on growth of hardwood trees in southern New York[1]

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Nitrogen fertilization rate trials (0–672 kg/ha) were established in seven second-growth mixed deciduous forest stands in southern New York, on well to somewhat poorly drained soils typical of better hardwood sites, with no history of fire or cultivation. Basal-area growth over 20 years was determined from increment cores of dominant and codominant trees. Significant growth response occurred only for black cherry (*Prunus serotina* Ehrh.). Nitrogen additions of 168–336 kg/ha increased growth 21% over 5–10 years. Ten-year basal-area growth response of sugar maple (*Acer saccharum* Marsh.) and white ash (*Fraxinus americana* L.) was less than in other fertilization studies. The lack of response is attributed to favorable nitrogen status of the soils, resulting from lack of disturbance over at least the last four decades and, possibly, atmospheric input of nitrogen.

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Des essais de fertilisation azotée à des taux variant de 0 à 672 kg/ha ont été effectués dans sept peuplements forestiers mixtes de seconde venue situés dans le sud de l'État de New York et établis sur des sols modérément à bien drainés typiques des meilleures stations à feuillus, n'ayant jamais subi d'incendie ou été cultivés. La croissance en surface terrière durant une période de 20 ans a été déterminée à partir de carottes prélevées sur des arbres dominants et co-dominants. Une réponse significative en croissance a été décelée seulement pour le Cerisier tardif (*Prunus serotina* Ehrh.). L'addition d'azote à des taux variant de 168 à 336 kg/ha a augmenté la croissance de 21% durant une période de 5–10 ans. La réponse en croissance décennale en surface terrière de l'Érable à sucre (*Acer saccharum* Marsh.) et du Frêne d'Amérique (*Fraxinus americana* L.) a été moindre que dans le cas d'autres essais de fertilisation. Le manque de réponse est attribué au statut favorable de l'azote dans le sol par suite de l'absence de perturbations durant au moins les quatre dernières décennies et possiblement à l'action de l'azote atmosphérique.

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TABLE 1. Stand characteristics and treatment designs at seven locations in New York State

	Soils	DBH range[a] (cm)	No. of plots	Plot design	Treatment: Initial (yr)	Treatment: Material	Treatment: Rates[b] (kg/ha)	Species sampled for this study
Cattaraugus	Gilpin, channery SL, Rayne SL, Typic Hapludults	23–51	12	RIB	1968	NH_4NO_3	0, 84, 168, 336, 504, 672	BC, WA, SM
Whig Street	Wharton SL, Aeric Hapludults	21–52	8	RCB	1968	NH_4NO_3	0, 168, 336, 504	WA, SM
Connecticut Hill	Mardin SL, Typic Fragiochrepts	21–44	8	CRD	1967	Urea NH_4NO_3	0, 168, 336, 672	SM
Chenango Black cherry	Bath SL, Typic Fragiochrepts	23–59	12	CRD	1968	NH_4NO_3	0, 168, 336, 504, 672	SM
Maple–basswood	Mardin SL, Typic Fragiochrepts	20–31	12	RCB	1969	NH_4NO_3	0, 168, 336, 504, 672	BC, WA, SM
Schoharie	Lordstown, Grav SL, Typic Dystrochrepts	19–62	14	RCB	1969	NH_4NO_3	0, 168, 336, 504, 672[c]	BC, SM
Hooker Hill	Lordstown, Typic Dystrochrepts	17–31	9	RCB	1969	NH_4NO_3	0, 168, 336, 504	WA, SM

NOTE: SL, silt loam; RIB, randomized incomplete blocks; RCB, complete design; CRD, completely randomized design; BC, black cherry; WA, white ash; SM, sugar maple.
[a]Range of sampled dominant and codominant trees.
[b]Plots were retreated with same amounts and type of material 5 years after initial treatment, except that 672 kg/ha was applied to the plots at Whig Street that had received 504 kg/ha initially, and Connecticut Hill was refertilized with NH_4NO_3 instead of urea.
[c]An extra treatment was applied in each replication of 504 kg/ha N and 252 kg/ha P as triple superphosphate.

Introduction

The first extensive experiments in forest fertilization in the United States were conducted by Mitchell and Chandler (1939) about 50 years ago. Their results from two locations in southern New York showed that northern hardwood species differed in response to added nitrogen (N). Comparing foliar analyses from other hardwood sites in the northeastern United States with critical values established by their own experiments, they concluded that 20% of the sample population was N deficient and an additional 65% N limited.

To test the applicability of Mitchell and Chandler's (1939) results to better sites, we established fertilizer rate experiments in natural hardwood stands across southern New York, over a 3-year period beginning in 1967.

The experiments were designed to test response to N. Only results for sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), and black cherry (*Prunus serotina* Ehrh.) are presented.

Materials and methods

Locations

The seven sites were selected in managed uniform medium pole to small sawlog size stands of more desirable hardwoods in state forests in southern New York. Elevation of the stands was between 518 and 692 m and total annual precipitation was 761–1151 mm. Long-term mean annual temperature was 6.1–7.8°C. Soils ranged from well to somewhat poorly drained. Table 1 summarizes various stand characteristics. Detailed descriptions of the locations and treatments are given elsewhere (Stanturf 1983).

Sample design

All experiments were rate trials, with from 0 to 672 kg/ha of N broadcast in each of two applications, 5 years apart. Ammonium nitrate was used, except that urea was used for the first application at the Connecticut Hill location. At Schoharie, phosphorus (P) was added. Experimental treatments are summarized in Table 1. Although layouts varied, treatments were replicated at least twice at each location. Each treatment plot (0.1 or 0.06 ha) contained a 0.01-ha interior measurement plot and was separated from adjacent plots by 6.1-m isolation strips.

After 10 years, annual radial growth of dominant and codominant trees over a 20-year period was obtained from increment cores taken at breast height. One core, or two cores 90° apart, were taken. All trees were cored except at Hooker Hill and Schoharie, where at least 10 sugar maple and 3 trees each of the other species were cored on each plot.

Cores were stored in water containing formaldehyde and measured on an Addo-X instrument (Ecklund 1950) to the nearest 0.01 mm. When two cores per tree were available, measurements were averaged for analysis.

Foliage samples were taken from the upper crown of one to three dominant sugar maple and white ash and from two understory seedlings per treatment at Connecticut Hill, near the end of the 1979 growing season. This material was dried at 68° C, ground, and analyzed for total Kjeldahl N.

Statistical analysis

Tree core data were manipulated to provide several response variables in addition to radial increment. These included annual basal-area (BA) increment following treatment, relative BA increment (Safford 1973), and BA increment between treatment intervals. (Radial growth in successive years was highly correlated.)

A mean annual pretreatment growth rate was calculated for each tree, using 10-year BA increment before treatment, and was used in analysis of covariance in preference to crown class to take into account initial differences in growth rate and tree size. (Crown class observed 10 years after fertilization could not be assumed to be independent of treatment effects.)

Growth variables were examined separately for species and location by analysis of covariance, nested design (Fryer 1966; Snedecor and Cochran 1967). Adjusted treatment means for white ash, black cherry, and sugar maple BA increments were pooled over locations to assess treatment effects in individual years. This meant that numbers of locations and rates were not equal. (Pooling was

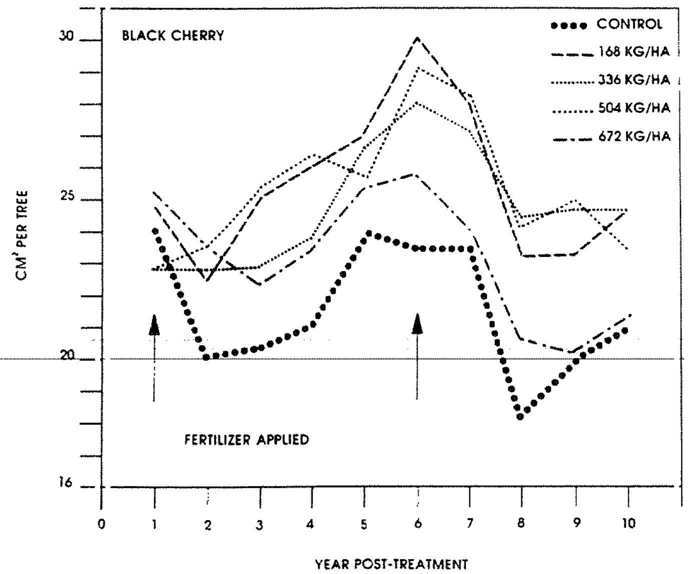

FIG. 1. Annual response of black cherry basal-area increment to added nitrogen; pooled data from four locations.

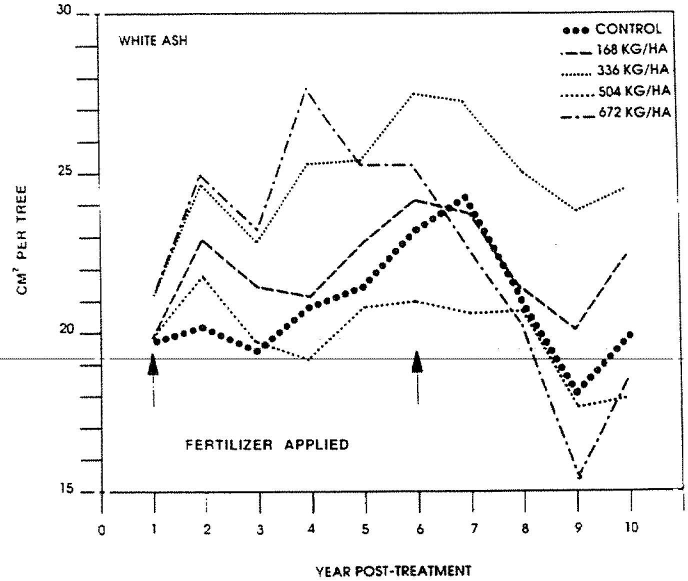

FIG. 2. Annual response of white ash basal-area increment to added nitrogen; pooled data from five locations.

based on the year following treatment, not the calendar year.) Differences among treatment means were tested for significance (p = 0.05) by means of orthogonal contrasts (Allen and Cady 1982). The highest r^2 value and lowest coefficient of variation from the analysis of covariance were for mean annual BA increment per individual tree. Analysis of variance showed that the level of P plus N at Schoharie was not significantly different from the N level alone; hence, these data were pooled.

Results

No foliar samples were collected before treatment. At the Connecticut Hill site, samples of sugar maple and white ash foliage collected 6 years after the second application showed that no difference among treatments remained. Assuming that the foliar N levels at this time were similar to those before fertilization, the stand was initially within the area of Mitchell and Chandler's (1939) response curve, indicating that added N should have produced additional growth. This did not occur.

Black cherry

Black cherry was the most responsive species at four locations (Fig. 1). Basal-area increment at all levels of added N exceeded control plot growth after the 1st year, significantly so in the 3rd year (p = 0.001). Quadratic and cubic effects were significant. The largest absolute increase was 6.7 cm^2/tree in year 3 at the lowest rate (168 kg/ha), representing a 33% increase over growth of the controls (Fig. 1). Growth at the highest rate (672 kg/ha) in the first 3 years declined below that of all other treatments except the control. Mean growth in all fertilized treatments declined in year 7, then declined abruptly in all treatments in year 8, with some recovery thereafter.

White ash

Basal-area increment of fertilized white ash exceeded that of controls in the 2nd and 3rd years following initial treatment (Fig. 2). Only trees fertilized with 336 kg/ha N maintained greater growth than controls over the entire 10 years.

The main effect of treatment was not significant in any year. The absence of response at 504 kg/ha may have accounted for nonsignificance in most years, and caused nonlinear (quartic) effects to be significant in years 4, 5, and 6. Nine of 15 trees composing this treatment came from two stands whose growth was less than that of controls during the entire experiment. During the first 5 years, growth at the 672 kg/ha rate was 22% greater than that of controls, but declined to 4% below that of the controls during the second interval. All trees grew less in year 8 than in previous years (Fig. 2), as did black cherry. Of the fertilized white ash, however, only those trees given the 672 kg/ha treatment showed a decline in year 7. White ash also differed from black cherry in that recovery of growth did not begin until year 10.

Sugar maple

The main effect of N over seven locations was slightly reduced growth of dominant and codominant sugar maple (Fig. 3). Negative effects were marginal in year 8 (p = 0.06) and statistically significant in years 9 and 10 (p = 0.001). Percent reductions in growth were progressively greater from year 7 through year 10. In a few instances, fertilized trees grew more than the controls, but increases were less than 10% and not significant. Following the second fertilization, growth at all levels of N was less than that of controls, and especially so at 504 and 672 kg/ha. As with black cherry, rates of sugar maple growth declined in year 8, with recovery in year 10.

Discussion

The results raise three issues: (*i*) the small magnitude of responses compared with those expected from the findings of Mitchell and Chandler (1939) and Chandler (1943); (*ii*) comparative responses of the three species; (*iii*) the marked growth reduction in all species and treatments in years 8 and 9. Table 2 compares the radial growth of white ash in the present study with that on the Arnot Forest location of Mitchell and Chandler (1939) and Chandler (1943). Experimental design, treatment rates, and N sources differ between the two studies. Nevertheless, growth of unfertilized trees in the present study was three times greater than at the Arnot site, where radial growth of the controls averaged 1 mm/year (Mitchell and Chandler 1939; Chandler 1943).

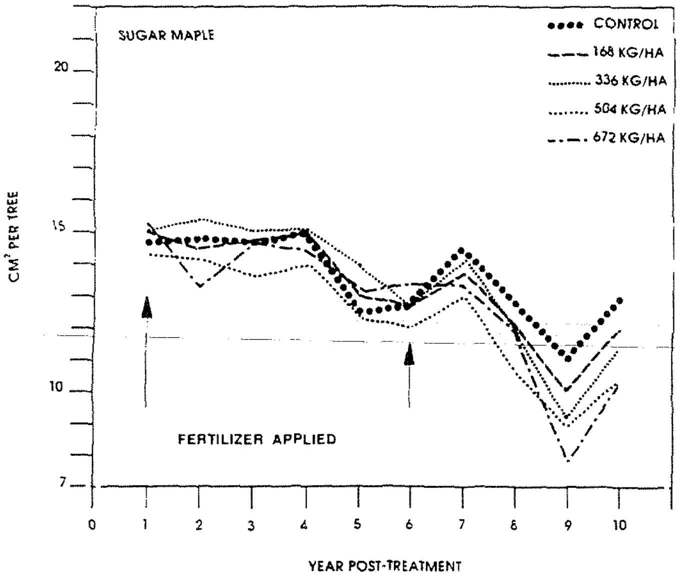

FIG. 3. Annual response of sugar maple basal-area increment to added nitrogen; pooled data from seven locations.

TABLE 2. Radial growth (mm) of white ash following various rates of nitrogen fertilization; comparison of results from the Arnot Forest (Mitchell and Chandler 1939; Chandler 1943) with means from the present study

Rate	Year 1	2	3	4	5	Source
0 kg/ha	0.9	1.0	0.9	0.9	1.0	Chandler 1943[a]
	2.6	2.6	2.5	2.6	2.6	Present study[b]
168 kg/ha	2.5	3.0	2.6	2.4	2.4	Present study
288 kg/ha	0.9	2.4	2.3	2.2	2.1	Chandler 1943
336 kg/ha	2.5	3.0	2.7	2.7	2.6	Present study
504 kg/ha	2.2	2.4	2.1	1.9	2.1	Present study
576 kg/ha	1.1	2.9	3.3	2.4	2.4	Chandler 1943
672 kg/ha	2.6	2.9	3.0	3.3	2.8	Present study
868 kg/ha	1.0	3.8	3.4	3.1	2.9	Chandler 1943

[a]Original experiment at one location (Arnot Forest, Schuyler County, New York), described by Mitchell and Chandler (1939).
[b]Replicated treatments at five locations (0, 168, and 336 kg/ha), three locations (504 kg/ha), or two locations (672 kg/ha).

This corresponds to the lowest growth rates in Trimble's (1969) study of white ash in West Virginia, and suggests that the burned site studied by Mitchell and Chandler (1939) was low in fertility. At the highest N rates, Mitchell and Chandler observed radial increments 280% greater than control values after 2 years. In contrast, the greatest increase obtained in the present study was 27%.

An initial question was whether the marked responses to N observed by Mitchell and Chandler (1939) in part of the same region were applicable to the better hardwood sites today. The much lower response of sugar maple and white ash in the present study may be attributed in part to the longer term of the study, or possibly to pooling of data from four to seven locations compared with two in Mitchell and Chandler's. More importantly, however, it appears that the stands of the present study were better supplied with N.

The more than 40 years separating the termination of the two studies has been a period of remarkably little disturbance in these stands. Fire has been essentially absent since the early decades of the present century. Mitchell (1972) commented that the soils of the Black Rock Forest locations were low in organic matter and N as a result of numerous fires in the 19th century. In the present stands, only light thinnings have been carried out since the stands came into state ownership in the 1930s.

Another factor contributing to a more favorable N status may have been increased atmospheric input of N since the 1940s. Input during the 1920s and 1930s was about 5 $kg \cdot ha^{-1} \cdot year^{-1}$ (Lyon et al. 1952). Nitrate plus ammonium inputs since then appear to have averaged no more than 10 $kg \cdot ha^{-1} \cdot year^{-1}$ (Pack 1980).[5] This increase, accumulated over 30 years, represents an appreciable addition to the soil N pool which was lacking before postwar industrialization.

Applied N did not persist in vegetation or soil. The foliar N values of sugar maple on Connecticut Hill indicate no difference among treatments. The foliar N values of over- and under-story sugar maple were not significantly different, a phenomenon noted before (R.F. Chandler, 1947, personal communication). The failure to detect elevated foliar N levels after the cumulative addition of 1344 kg–ha is strong evidence that N did not persist in the vegetation. Moreover, in the present study, intensive sampling of soils at four locations failed to reveal treatment differences in total N content of either the organic layer or the upper (0–10 cm) mineral soil (J.A. Stanturf and E.L. Stone, in preparation).

Black cherry was not studied by Mitchell and Chandler (1939) but may be considered a "demanding" species (Auchmoody 1982; L.R. Auchmoody personal communication, 1978; Ellis 1979). Our results confirm that black cherry grows faster at all rates of added N, although response fell off somewhat at the highest rate (672 kg/ha). The higher application rates produced negligible benefit, as there was little difference in mean responses to 168 and to 504 kg/ha. L.R. Auchmoody (personal communication, 1981) noted similar results in northwestern Pennsylvania.

White ash was classified as "N-demanding" by Mitchell and Chandler (1939), and would be expected to respond markedly to N unless available N was already sufficient. The effect of treatment was not statistically significant in any of the 10 years of the experiment. Year to year variation was large, however, even in the adjusted mean values (Fig. 2). Except for the 504 kg/ha treatment, white ash responded well in the first 5 years, with the greatest response at the 336 and 672 kg/ha rates.

Mitchell and Chandler (1939) classified sugar maple as "intermediate" in its N requirement. To be consistent with a hypothesis of better site quality in the present study, sugar maple should not respond much to the added N. Indeed, sugar maple emerges as a remarkably unresponsive species. There was no consistent positive response to N, and growth rates actually declined with treatment following the second application. At two locations, a significant (p = 0.05) positive response to fertilization was obtained. This was associated with temporarily lower crown densities of other species (Stanturf and Stone 1985) as a result of defoliation in one stand and cultural work in the other.

[5]L.R. Auchmoody, unpublished data on file at the Forestry Sciences Laboratory, Warren, PA; W.W. Knapp, unpublished data on file at the Agronomy Department, Cornell University, Ithaca, New York.

Such a lack of response differs from the findings of Mitchell and Chandler (1939), Safford (1973), Carmean and Watt (1975), and Lea et al. (1979). On the other hand, several other studies (Ellis 1979; Leaf and Bickelhaupt 1975; Stone 1977; Stone and Christenson 1974) have shown a lack of response of sugar maple. Negative effects of fertilization, however, have been demonstrated only for suppressed northern hardwoods (Safford 1973; Stone 1977), and probably result from greater shading by the responding dominant and codominant trees.

The slow overall decline in sugar maple growth (Fig. 3) is attributed to increasing crown competition. All plots had been unthinned for 13-20 years. Growth of the residual stand plus ingrowth over this period intensified competition. In general, the measured trees constituted 60-90% of the plot BA, and dominant and codominant sugar maple made up 0-70% of the BA of individual plots. Sugar maple was two to three times more abundant than black cherry and five to ten times more abundant that white ash within respective treatments. As all trees sampled were dominant or codominant at the end of the experiment, competition rather than suppression accounts for the decline.

In all three species, growth of controls declined in years 8 and 9. We have summarized elsewhere (Stanturf and Stone 1985) evidence indicating widespread defoliation by forest tent caterpillar, fall cankerworm, cherry scalloped shell moth, and linden looper, as well as frost damage at various locations during this period. The evidence for defoliation in these stands was circumstantial, although at one location there was direct evidence that insects fed preferentially on some species (Stanturf and Stone 1985).

Pooling data from several locations and for different calendar years would be expected to obscure the effects of defoliation and weather on individual tree growth rates. On the other hand, the effect of herbivores lasts over several seasons as insect populations build and then decline. Thus, black cherry, indeterminate in growth, should recover faster from defoliation than the relatively determinate growth sugar maple and white ash (Kulman 1971). The sharp decline in growth of controls in the same year for all three species is the result of combining the effects of successive and concurrent defoliation outbreaks and frost damage, rather than a single agent affecting the three species across the state.

Heavily fertilized trees may be more susceptible to attack by insect herbivores, resulting in growth reductions. The decline in sugar maple growth in years 7-9 is related to N rate (Fig. 3). Many plants produce secondary compounds that reduce their susceptibility to herbivores (Mattson 1980; Mattson and Addy 1975), and production of such secondary compounds may be inversely related to nutrition (Mattson 1980; Toumi et al. 1984) because of competition within the plant for carbon.

Thus, it appears that N availability is not a factor limiting growth of pole- and sawlog-size stands in southern New York on reasonably good sites with these basal areas. Thinning would probably be necessary to obtain greater response to fertilization (Lea et al. 1979; Miller 1981), at least for sugar maple. Nitrogen at rates of 168–336 kg/ha would probably increase BA growth of demanding species such as black cherry and white ash up to 21% more than that of unfertilized trees over a 5- to 10-year period, even without thinning. Further experiments combining thinning with fertilization are needed to quantify the increased growth that might result from more intensive management of northern hardwoods.

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